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MOISTURE SORPTION CHARACTERISTICS OF WHITE MULBERRY (*MORUS ALBA*) AS A NATURAL ALTERNATIVE TO SUGAR

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Abstract

The current research of three different institution scientists in Plovdiv, Bulgaria concerning moisture sorption characteristics is focused on the white mulberry. Known as a bioproduct rich in bioactive compounds, *Morus Alba* is considered to be a good source and a natural substitute for sugar since it provides a better control on diabetes. The present study aims to investigate the moisture sorption isotherms of white mulberry using the static gravimetric method.

We examined the adsorption and desorption processes at three different temperatures - 10, 25, and 40 ^{0}C - and eight relative air humidity's in the 11 - 87% range. These selected parameters were analyzed because they testify to the keeping qualities of the product in stores and on the market. The obtained equilibrium sorption isotherms were described by means of the modified three-parameter Halsey, Henderson, Chung-Pfost and Oswin models and evaluated with selected criteria - mean relative error, standard deviation and distribution of residuals. With the help of the linearization of the Brunauer-Emmet-Teller equation, we obtained data on the prediction of monolayer moisture content at 10, 25, and 40 ^{0}C for adsorption and desorption.

The initial moisture content of white mulberry was 13.54%, after drying above P_2O_5, it decreased to 9.57% and following hydration above distilled water* it became 20.02%. As a result of the adsorption and desorption studies, under the conditions of constant water activity, the sorption capacity of the white mulberry increases with the decrease in temperature. Adsorption and desorption isotherms are S-shaped (Type II in Brunauer's classification) typical of most food products.

According to the used criteria, we recommend the modified Halsey since it best describes the sorption characteristics of white mulberry evaluating the suitability of the models. The calculated monolayer moisture content values were within the 8.86% - 9.91% range for adsorption and within the 10.85% - 13.07% range for desorption.

***Key words**: White mulberry, Morus Alba, Sorption isotherms, Monolayer moisture content.*

1. Introduction

The moderate daily consumption of natural products, which sustains and improves the human immune system, is a response to aggravating pandemic conditions. Fruit and vegetables are excellent sources of indispensable vitamins, fiber, and antioxidants which both stimulate and prevent or inhibit the development of disease-causing organisms. Health authorities, as well as most medicine journals, recommend a greater consumption of fruit, vegetables and whole-grain food (70% of the daily intake) and a reduction of convenience foods due to their minimum or limited content of vitamins and minerals. Consumer requirements include a variety of natural, regionally grown food with scientifically proven health benefits [1, 2, and 3].

The leaves and berries of white mulberry *Morus alba L.* (*Moreaceae* family), which is quite common in Bulgaria, have potent biological activity. It is widely known that July- and August-ripened berries are rich in antioxidants, prevent against diabetes, and demonstrate immunomodulatory and anti-inflammatory activity, anti-obesity activity, and hepatoprotective and renoprotective activity [4]. What is more, white mulberry is an excellent source of A, B2 and C vitamins and minerals such as potassium, sodium, calcium, magnesium, phosphorus, and pectin. Due to its flavonoid content and rich functional content, mulberry is very popular in folk medicine for the treatment of diseases of the heart, liver, kidneys, etc. White mulberry has a low glycemic index and is used as a natural substitute for sugar. More specifically, data indicates that the activity of mulberry polyphenols helps in dealing with increased blood sugar levels, lipid accumulation, inflammation, and other related problems [5, 6].

Water activity is an important factor directly affecting the behavior of food products during processing, transportation, and storage. When controlling its values, we can very well predict and prevent against imminent undesirable chemical reactions and/or initiate/ provoke specific physical effects. Moreover, the water activity of the product, the relative air humidity of the environment and temperature are interdependent parameters which strive for balance [7, 8]. The changes in the equilibrium moisture values of the product as regards different ranges of water activity and temperature are manifested here by means of experimentally constructed adsorption and desorption isotherms. The identification and understanding of the sorption characteristics will be informative as to how to preserve as long as possible the quality parameters of bioactive substances whose amount depends on the parameters listed above and this will contribute to the extended consumption of the product [9, 10].

Known as a bioproduct rich in bioactive compounds, *Morus Alba* is considered to be a good source and a natural substitute for sugar since it provides a better control on diabetes. The present study aims to investigate the moisture sorption isotherms of white mulberry using the static gravimetric method.

2. Materials and Methods

2.1 Materials

The study used white mulberry produced in Turkey, purchased in Bulgaria by "Internet café-BG" Ltd, packed by "Zoya bg Organic Shop" possessing Organic-Certificate (BIO production).

Physico-chemical composition of white mulberry (*Morus Alba*) had already been determined by the manufacturer: energy value of 1,377 kJ/329 kcal; 1.5 g fat, of which 0.03 g saturated; 74.6 g carbohydrates, of which 37.7 g sugars; 4.2 g protein; and 0.1 g salt.

2.2 Methods

2.2.1 Sorption characteristics

In order to identify the sorption characteristics of dried white mulberry, we applied the static gravimetric method, as has also been done by Demarchi *et al.*, [11], Martínez-Las Heras *et al.*, [12], and Bogoeva and Durakova [8]. We chose three temperatures - 10 ^{0}C, 25 ^{0}C, and 40 ^{0}C - pointing to the most common temperature ranges in production and storage facilities. We obtained the water activity range (a_w= 0.1 ÷ 0.9) with the help of saturated salt solutions: LiCl, CH_3COOK, $MgCl_2$, K_2CO_3, $MgNO_3$, NaBr, NaCl, KCl. A detailed description of the method used has been included in Bogoeva [13]. The moisture content (%) was calculated according to AOAC 960.39 [14].

In order to fully describe the sorption characteristics of white mulberry, we selected 4 modified mathematical models, of Chung-Phost, Halsey, Oswin and Henderson, as follows:

Modified Chung-Pfost

$$a_w = exp\left[\frac{-A}{t+B}\exp(-CM)\right] \quad (1)$$

Modified Halsey

$$a_w = exp\left[\frac{-\exp(A+Bt)}{M^C}\right] \quad (2)$$

Modified Oswin

$$M = (A+Bt)\left(\frac{a_w}{1-a_w}\right)^C \quad (3)$$

Modified Henderson

$$1 - a_w = exp[-A(t+B)M^C] \quad (4)$$

Where: M is the average moisture content, % d.b.; a_w is the water activity, decimal; *A*, *B* and *C* are coefficients; *t* is the temperature, ^{0}C.

We chose the most suitable model, able to describe in full the sorption characteristics obtained, on the basis of the mean relative error P (%); the standard error of moisture (SEM) and the randomness of residuals:

$$P = \frac{100}{N}\sum\left|\frac{M_i - \hat{M}_i}{M_i}\right| \quad (5)$$

$$SEM = \sqrt{\frac{\sum(M_i - \widehat{M}_i)^2}{df}} \quad (6)$$

$$e_i = M_i - \widehat{M}_i \quad (7)$$

Where: M_i and $\widehat{M}_i$ are experimentally observed and predicted by the model value of the equilibrium moisture content; *N* is the number of data points; *A*, *B* and *C* are coefficients; *df* is the number of degree of freedom (number of data points minus number of constants in the model).

The Brunauer-Emmett-Teller (BET) model was linearized to calculate the monolayer moisture values of white mulberry, as follows [15]:

$$M = \frac{M_e C a_w}{(1 - a_w)(1 - a_w + C a_w)} \quad (8)$$

Where: *M* is the MMC, % d.b.; a_w is the water activity, decimal; *C* is the coefficient.

To calculate monolayer moisture, the BET model (8) was linearly transformed, as follows:

$$\frac{a_w}{(1 - a_w)M} = P + Q a_w \quad (9)$$

The description of the method used is described in detail in an article by Bogoeva [13].

All tests were conducted in triplicate runs. The data presented is mean values and standard deviations.

However, we were not able to find any information concerning the moisture sorption characteristics of white mulberry (*Morus Alba*).

3. Results and Discussion

3.1 Moisture sorption analysis of white mulberry (*Morus alba*)

Due to its high water content during harvesting, white mulberry has a short shelf life which can be prolonged by means of dehydration [16]. Akbuluta and Durmus [17], point out that prior to dehydration the initial moisture content of fresh mulberry was approximately 80% (wet basis), whereas after heat treatment it amounted to 8% (wet basis). In the present study, the initial moisture content of white mulberry was 13.54%. Before being placed in hygrostats, the samples were pre-dried and moistened. After drying above P_2O_5 in a desiccator, it decreased to 9.57% and following hydration above distilled water it became 20.02%. Studying the sorption characteristics of dried white mulberry, we can obtain additional information on the behavior of the product under different conditions, i.e. temperature and relative air humidity. Knowing exactly how temperature and relative air humidity affect the product, we can control and prevent against some chemical, physical, and organoleptic changes in the product. Therefore, Tables 1 and 2 present the equilibrium moisture content at 10 ^{0}C, 25, ^{0}C and 40 ^{0}C for adsorption and desorption.

Table 1. Equilibrium moisture content of white mulberry (*Morus alba*) for adsorption

	10 ^{0}C			25 ^{0}C			40 ^{0}C		
Sel	a_w	**EMC**	**SD**	a_w	**EMC**	**SD**	a_w	**EMC**	**SD**
LiCl	0.113	**10.63**	0.06	0.113	**8.03**	0.18	0.112	**7.99**	0.87
CH_3COOK	0.234	**10.76**	0.21	0.225	**8.78**	0.23	0.201	**8.43**	0.62
$MgCl_2$	0.335	**12.43**	0.41	0.328	**12.21**	0.70	0.316	**10.46**	0.35
K_2CO_3	0.431	**16.93**	0.49	0.432	**16.45**	0.87	0.432	**15.44**	0.35
$MgNO_3$	0.574	**22.35**	0.93	0.529	**21.20**	0.89	0.484	**20.60**	0.14
NaBr	0.622	**27.29**	0.58	0.576	**23.43**	0.58	0.532	**20.78**	0.66
NaCl	0.757	**49.86**	0.74	0.753	**46.72**	0.41	0.747	**44.16**	0.44
KCl	0.868	**76.29**	0.24	0.843	**69.47**	0.61	0.823	**66.04**	0.47

Table 2. Equilibrium moisture content of white mulberry (*Morus Alba*) for desorption

	10 ^{0}C			25 ^{0}C			40 ^{0}C		
Sel	a_w	**EMC**	**SD**	a_w	**EMC**	**SD**	a_w	**EMC**	**SD**
LiCl	0.113	**13.78**	0.28	0.113	**9.20**	0.27	0.112	**7.56**	0.35
CH_3COOK	0.234	**14.66**	0.34	0.225	**10.61**	0.33	0.201	**9.64**	0.37
$MgCl_2$	0.335	**16.26**	0.34	0.328	**13.57**	0.15	0.316	**12.21**	0.25
K_2CO_3	0.431	**22.00**	0.33	0.432	**20.692**	0.60	0.432	**17.72**	0.25
$MgNO_3$	0.574	**24.60**	0.40	0.529	**23.01**	0.64	0.484	**19.28**	0.84
NaBr	0.622	**26.42**	0.42	0.576	**23.89**	0.03	0.532	**23.25**	0.59
NaCl	0.757	**47.35**	0.51	0.753	**46.02**	0.61	0.747	**44.41**	0.19
KCl	0.868	**82.19**	0.60	0.843	**66.55**	0.25	0.823	**61.68**	0.17

Legend: * Stages of preparation of the product before its placement in hygrostats (see the materials and methods section).

Throughout the years, it has been recurrently proven that the increase in temperature leads to the decrease in equilibrium moisture under the conditions of constant water activity, which is evident in our study as well [18, 8].

In order to determine the type of isotherms following Brunauer's classification, in Figure 1 we show the isotherms obtained for adsorption and desorption at 10 ^{0}C.

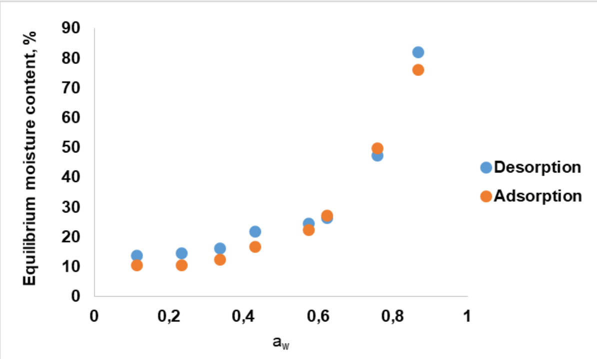

Figure 1. White mulberry isotherms at 10 ^{0}C

At 10 ^{0}C the isotherms are S-shaped, which means that they belong to Type II in Brunauer's classification, a type typical of most food products [19, 20, 8, and 13]. They are comparable to the adsorption and desorption isotherms at 25 ^{0}C and 40 ^{0}C.

On the basis of our literature review, we opted for four modified models in order to describe the sorption isotherms of dried white mulberry: Oswin, Halsey, Henderson and Chung-Pfost. The results obtained for model coefficients (A, B, C), mean relative error (P, %) and standard error of moisture (SEM) as well as the distribution of the residuals can be seen in Tables 3 and 4.

Taking into account the results obtained and the criteria applied to evaluate the suitability of the models, we recommend the modified Halsey for the description of the sorption characteristics of white mulberry.

The linearization of the BET model with equation 9 produces monolayer moisture values for all three temperatures - 10 ^{0}C, 25 ^{0}C, and 40 ^{0}C - and for the two sorption processes of adsorption and desorption, as presented in Table 5.

Table 5. Monolayer moisture content of white mulberry (*Morus alba*)

Process of:	Temperature, ^{0}C		
	10	25	40
Adsorption	9.28	9.91	8.86
Desorption	12.06	13.07	10.85

Analyzing the results, we can conclude that the MMC values at 25 ^{0}C are higher than those at 10 ^{0}C and 40 ^{0}C. MMC values are calculated in order to determine the moisture range the product can fall in, which we think will guarantee the preservation of its quality characteristics for a longer period of time.

4. Conclusions

- We determined the equilibrium moisture of white mulberry at the temperatures of 10 ^{0}C, 25 ^{0}C, and 40 ^{0}C for eight different water activities in the 0.1 - 0.9 range. The sorption capacity of the product under study increases with the decrease in temperature under the conditions of constant water activity.
- Adsorption and desorption isotherms are *S*-shaped (Type II in Brunauer's classification). Having in mind the criteria for evaluating the suitability of the models, we recommend the modified Halsey since it best describes the sorption characteristics of white mulberry.
- Monolayer moisture content of the white mulberry was identified at 10 ^{0}C, 25 ^{0}C, and 40 ^{0}C, falling within the 8.86% - 9.91% range for adsorption and within the 10.85% - 13.07% range for desorption.

Table 3. Adsorption: Model coefficients, P, SEM, and Distribution of residuals for modified Oswin, modified Halsey, modified Henderson, and modified Chung-Pfost

Model	A	B	C	P	SEM	Residuals
Oswin	19.804	0.031	0.720	14.86	3.96	Non-random
Halsey	**3.058**	**-0.003**	**1.123**	**9.20**	**3.25**	**Random**
Henderson	0.0003	107.310	0.961	21.86	5.70	Non-random
Chung-Pfost	239.495	0.110	35.696	32.52	19.72	Non-random

Table 4. Desorption: Model coefficients, P, SEM, and Distribution of residuals for modified Oswin, modified Halsey, modified Henderson, and modified Chung-Pfost

Model	A	B	C	P	*SEM*	*Residuals*
Oswin	23.340	-0.040	0.659	13.59	3.19	Non-random
Halsey	**3.730**	**-0.009**	**1.260**	**9.69**	**3.32**	**Random**
Henderson	0.0003	60.729	1.062	21.30	6.53	Non-random
Chung-Pfost	530.764	0.055	175.618	23.63	6.98	Non-random

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